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**ANNAMÁRIA KONCZ**

# Preliminary risk analysis of test laboratories

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# 1 Summary

*During my professional career, I have recognized the importance of risk analysis in the industry and in the service sector as well. FMEA, despite its shortcomings is an applicable method for risk assessment, but I have noted that with the development of traditional risk analysis methods new flexible ways of risk assessment can be created. I find this idea significantly important, because the current technological developments demand flexible and adaptable solutions. For the operation of lithium-ion testing facilities mandatory fire and explosion safety analysis are needed, but these does not cover the complexity of operational safety. Traditional FMEA uses only three factors (Severity, Occurrence, and Detection) which do not cover the influencing conditions. In other aspects, the specialty of this field is derived from the fact that a Process-FMEA itself is not enough to cover the risks, as the examined processes are abuse tests. There is high impact of uncertainty in accordance with Design FMEAs, as they are often missing from the manufacturer side. (Because in case of non-automotive batteries FMEA is not mandatory.)*

*During the establishment of test facilities, the highest level of safety is a preliminary condition, but there are circumstances (lack of time or expertise) in which fast decisions are needed. The aim of my work is to establish a new method, which fits the purposes of practical work. With the usage of fuzzy logic, I have created a preliminary risk analysis approach that solves the aforementioned barriers of risk analysis methods.*

# 2 History of the research

Since the 1980s the development of lithium-ion batteries is ongoing, with the improvements of researchers like Stanley Whittingham, John Goodenough and Josino Akira, who were awarded with the Nobel Prize in Chemistry in 2019 [1]. Their inventions revolutionized the market of portable energy source devices. Nowadays, lithium-ion batteries are inevitable parts of our lives: laptops, handheld tools, electrical devices, and even e-mobility devices: like e-bikes, e-scooters, hybrid and electric cars are equipped with them. The number of applied cells can be at least one in case of handheld tools, and it can reach even thousands in case of electric cars. Besides the excessive number of cells used for e-mobility purposes, the weight of the applications is significant as well.

The demand for lithium-ion batteries is high as their application is widespread in the manufacturing sector. During the COVID 19 pandemic, the need for lithium-ion batteries increased as the shift to home office triggered household handicraft works, and the demand for portable electric devices, such as laptops, etc. In the following years, a shortage of lithium-ion battery supply is forecasted, due to material shortage (due to the excessive time of mining, and exploitation) [2].

The aforementioned technological and market aspects have a significant impact on battery testing facilities, as the demand for their services is not balanced; there are expansive peaks in workload. This accelerates the battery testing projects that leads to the decrease of preparation times. This way, the test intervals are approaching the technological time needs. Under these given circumstances, testing safety gains more and more importance, as lithium-ion battery tests are potentially hazardous and safety critical.

# 3 Objective of the research

During my research my aim was to create a new model for the preliminary risk analysis of Li-ion battery test laboratories, which eases the work and project preparation of test engineers. Whilst carrying out my research the goals were the following:

- Definition of input factors,
- Definition of rating catalogues,
- Definition of fuzzy systems/subsystems,
- Definition of system output,
- Validation of results.

# 4 Research methods and limitations

During the preparation of my thesis, I have divided my research in three parts. In the first part, I have presented the basic structures and features of lithium-on batteries, the possible risks of lithium-ion batteries and the standardized lithium-ion battery tests. In the second part, I have examined specialized literature in terms of risk analysis methods, conventional FMEA and non-conventional FMEA methods. In the third part, I present the Hierarchical Overall Risk Analysis (HORA) method, which I have developed. The complex fuzzy logic based method was modelled with Matlab, and Taguchi's $L_{75}$ $5^8$ $15^1$ experimental design was used for the design of validation experiments.

In my thesis, I have taken into consideration the UN 38.3 [3] transport safety tests as a basis (on battery level). In my work, I did not analyze cell level tests and other standardized or customized tests. In the thesis I did not analyze the electrochemical risks, I have only represented a generalized level of risks. My thesis does not cover the aspects of automotive battery risk analysis. The suggested model is not for system optimization, but for preliminary risk analysis.

# 5 New scientific results

- **Thesis (T1)**: *I have **verified** that a preliminary risk assessment is required for standardized laboratory testing of lithium-ion batteries.*

Based on my practical experience, during my research I have analyzed my hypothesis 1 (H1). By summarizing the variety of Li-ion batteries and the wide range of test processes in Chapter 1, I have demonstrated the necessity of a preliminary risk analysis method, which is a practical tool to predetermine system related effects. The foreseeable test-related effects help test engineers to prioritize their test projects. Therefore, my **T1** thesis is proved by my results of my scientific research process that is supported by my publications **[KA1]**, **[KA2]** and **[KA3]**.

- **Thesis 2 (T2)**: *I have **proven** that conventional FMEA-based analyses are not sufficient for a preliminary risk assessment of a lithium-ion battery-testing laboratory.*

Based on my professional experience, and the findings stated in specialized literature, I have evaluated my hypothesis 2 (H2), and published my results. During the literature review investigation, I have found proof about the shortages of the traditional Failure Mode and effect Analysis, according to Spreafico et al. [4], presented in Chapter 2. I have aligned the results of Spreafico et al. with the findings of Fantham and Gladwin [5]. With the comparison and review of a specialized Li-ion battery test process FMEA [6], I have identified gaps in the usage of the traditional FMEA method.

Therefore, my **T2** thesis is proved by my results of my scientific research process that is supported by my publications **[KA1]**, **[KA2]** and **[KA3]**.

- **Thesis (T3)**: *I have developed a new preliminary risk assessment method called Hierarchical Overall Risk Analysis (HORA).*

During the literature review process, I have identified those existing approaches (Chapter 2), that can be successfully merged to create a new method, with surplus considerations. In Chapter 2, I have detailed the similarities and differences of the existing methods and the suggested model, HORA.

Based on my research, and the outlined shortages of current preliminary risk analysis methods, and the basis of them, I have constructed a new preliminary risk analysis method (Chapter 3) according to my hypothesis 3 (H3), which considers the test processes and product features to be a whole system. As it is a fuzzy logic-based approach, it eases usage, and covers the shortages of information at product side. Therefore, I have proven my **T3** thesis by my results of the new established model, and I have supported by my publication [**KA3**].

- **Thesis (T3a)**: *I have **proven** the accurate operation of the system by involving experts (test engineers).*

For the validation process, I have used DoE considerations (according to Taguchi) [6], [7]. (The orthogonal array $L_{75}$ $5^8$ $15^1$ was the most fitting design [7].) The validation process was done with the help of experienced lithium-ion battery test engineers. According to their feedback, the model provides valid predictions. Therefore, I have proven my T3a thesis by my results of the new established model, and I have supported by my publication [**KA3**].

- **Thesis 3b (T3b)**: *I have **determined** the factors required for the preliminary risk analysis.*

Whilst developing the HORA model, I have introduced the factors *Occurrence, Controllability, Protection, Effectiveness*, and *Severity* /*Cost*. These factors are interpreted at different levels of the model. *Occurrence* and *Controllability* belong to Fuzzy subsystem$_1$ ($Risk_{product}$), *Protection* and *Effectiveness* belong to Fuzzy subsystem$_2$ ($Risk_{process}$), and *Severity*/*Cost* belongs to Fuzzy subsystem$_3$ ($Risk_{system}$).

Therefore, I have proven my **T3b** thesis by my results of the new established model, and I have supported by my publication **[KA3]**.

- **Thesis 3c (T3c)**: *I have **introduced** a combined Severity / Cost factor that can be used for the complex evaluation of technological events.*

Besides the technically related factors, factor *Severity*/*Cost* combines the battery test related effects from both the technical and economical side. During practical projects, the cost related considerations influence project priority as well.

Therefore, I have proven my **T3c** thesis by my results of the new established model, and I have supported by my publication **[KA3]**.

- **Thesis 4 (T4)**: *I have created customized rating catalogues to evaluate each factor (Occurrence, Controllability, Protection, Effectiveness, Severity / Cost) ensuring further adaptiveness of the proposed method.*

For the proper identification of each factor level, I have implemented rating catalogues (Chapter 3). With the help of the rating catalogues, the experts can determine the input factors with ease. Besides using linguistic variables, crisp values are represented in the rating catalogues as well as its comparison with the traditional Failure Mode and Effect Analysis method.

Therefore, I have proven my **T4** thesis by my results of the new established model, and I have supported by my publication **[KA3]**.

# 6 Recommendations for future usage

Further research will consider the applicability fuzzy signatures [8], solutions inspired by fuzzy control theory [9], cognitive maps [10], and rule base simplification techniques [11]. One possible future step is to create a decision-making (DM) application [12] in which the HORA model is expanded on. The aim of this future approach is to provide a highly efficient DM application with flexible thresholds. With the usage of a customized DM approach the preliminary analysis can be combined with a system-built decision-making tool that decreases time spent on project preparation tasks.

# 7 References

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# 8 Publications

## 8.1 Publications related to theses

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[KA2] A. Koncz: Transport safety testing of lithium-ion batteries and their risk concerning laboratory environment during tests, Proceedings of the 16th MINI Conference on Vehicle System Dynamics, Identification and Anomalies, Budapest, Hungary, Budapest University of Technology and Economics, manuscript accepted (2020)

[KA3] A. Koncz, Zs. Cs. Johanyák, L. Pokorádi: Hierarchical Overall Risk Analysis (HORA) Model for the Preliminary Risk Analysis of Lithium-Ion Battery Testing Laboratories, PROCEEDINGS OF THE ROMANIAN ACADEMY – SERIES A: Mathematics, Physics, Technical Sciences, Information Science (ISSN: 1454-9069), journal published by Editura Academiei Romane (Romanian Academy Publishing House), Calea 13 Septembrie, no. 13, S5, 050711, Bucharest, Romania, pp. 89-97

## 8.2 Further publications

[KA4] A. Koncz: A Hibamód- és Hatáselemzés alkalmazása napjaink autóiparában, Bánki Report, I. : 3. pp. 15-20. , 5 p. (2018)

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[KA6] A. Koncz, L. Pokorádi, Zs. Cs. Johanyák: Fuzzy logic in automotive engineering, Gradus, 5 : 2 pp. 194-200. , 7 p. (2018)

[KA7] A. Koncz, L. Pokorádi: 8D usage in the automotive industry, 18th IEEE International Symposium on Computational Intelligence and Informatics (CINTI) Proceedings (2018)

[KA8] A. Koncz: Failure Mode and Effect Analysis types in the automotive industry, Proceedings of the 16th MINI Conference on Vehicle System Dynamics, Identification and Anomalies, Budapest, Hungary, Budapest University of Technology and Economics, pp. 321-328. , 10 p. (2019)

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[KA11] A. Koncz: A 8D problémamegoldó technika, Repüléstudományi Közlemények, XXVII., 3 pp. 7-17, 11 p. (2015)

[KA13] A. Koncz: A lean szemlélet eszköztára, Gradus: pp. 229-241, 13 p. (2017)